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Review Article

# Neuroanatomy of Neurogenic Shock

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## Abstract

Neurogenic shock is thus defined as autonomic failure, leading to hypotension, bradycardia, and metabolic vasodilation. The primary pathology lies in the cessation of the sympathetic outflow following the spinal or brain stem injury insult. Thus, an understanding of the neuroanatomic substrate of neurogenic shock's pathophysiology is a prerequisite for a successful approach to diagnosis and therapy. Therefore, this narrative review will comprehensively discuss the neuroanatomic structures involved in the pathology of neurogenic shock, emphasizing their functional significance in the context of the impairment consequences.

**Keywords**

- neurogenic shock
- autonomic failure
- hypotension
- bradycardia
- sympathetic outflow
- spinal cord injury
- pathophysiology
- autonomic nervous system

## Introduction

Spinal cord injury at cervical or high thoracic levels may interrupt autonomic pathways, leading to neurogenic shock characterized by hypotension, bradycardia, and impaired thermoregulation due to loss of sympathetic control (see ►**Fig. 1**).[1] Spinal cord injury remains a significant public health burden worldwide because of its devastating impact on patients' quality of life and the considerable demands it places on health care systems.[2] Recent studies have emphasized that early recognition and hemodynamic stabilization significantly improve outcomes in patients with neurogenic shock, supporting prompt intervention protocols in acute trauma care.[3] This review will explore the neuroanatomical sites responsible for autonomic regulation and involvement in the pathophysiology of neurogenic shock.

## Neurogenic Shock

Neurogenic shock is classified among the distributive forms of shock, distinguished by systemic vasodilation and cardiovascular instability resulting from central autonomic pathway disruption.[4] It results primarily from injuries to the cervical and upper regions of the thoracic spinal cord, particularly at or above the T6 level, where sympathetic outflow to the heart and vessels is disrupted.[5] While spinal cord injuries are the most common cause, neurogenic shock may also develop due to brainstem lesions that interfere with autonomic regulatory nuclei.[6] Neurogenic shock is distinguished from the other forms of shock by the presence of hypotension and bradycardia, caused by unopposed parasympathetic activity.[7]

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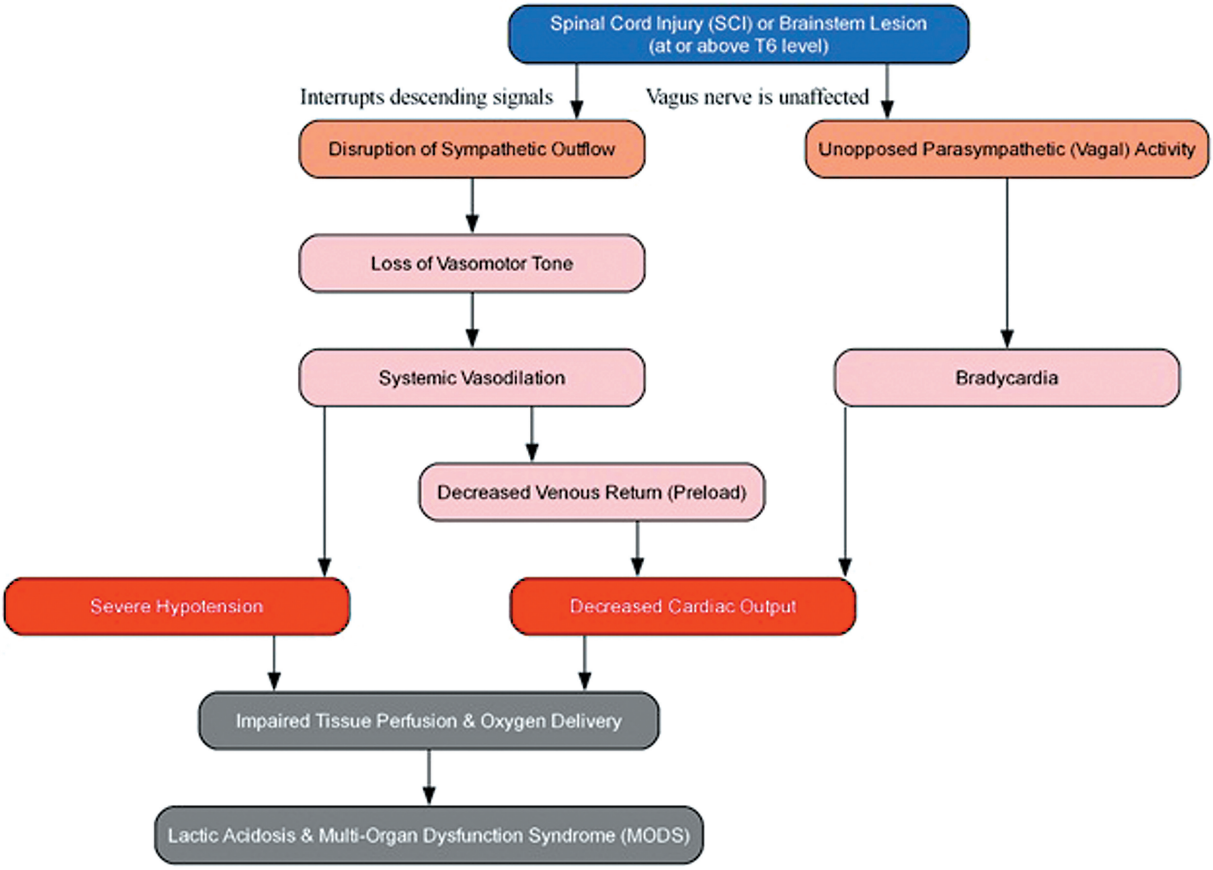
Spinal Cord Injury (SCI) or Brainstem Lesion (at or above T6 level)
Interrupts descending signals
Vagus nerve is unaffected
Disruption of Sympathetic Outflow
Unopposed Parasympathetic (Vagal) Activity
Loss of Vasomotor Tone
Systemic Vasodilation
Bradycardia
Decreased Venous Return (Preload)
Severe Hypotension
Decreased Cardiac Output
Impaired Tissue Perfusion & Oxygen Delivery
Lactic Acidosis & Multi-Organ Dysfunction Syndrome (MODS)

**Fig. 1** Pathophysiology of neurogenic shock.

## Neuroanatomical Basis of Neurogenic Shock

### The Autonomic Nervous System and Sympathetic Regulation

The autonomic nervous system (ANS) comprises two main branches: the sympathetic and parasympathetic divisions.[8] The sympathetic nervous system originates in the thoracolumbar spinal cord (T1–L2) and is responsible for maintaining vascular tone, heart rate, and blood pressure. Disruption of sympathetic pathways leads to vasodilation and bradycardia, hallmark features of neurogenic shock. Functional magnetic resonance imaging studies have shown diminished sympathetic activity and altered connectivity within cortical autonomic networks in patients with neurogenic shock, suggesting that higher brain centers may modulate systemic autonomic responses.[9] This highlights the complex neuroanatomical basis of sympathetic regulation and implies that cortical centers may also contribute to the autonomic imbalance observed in neurogenic shock.

### Brainstem Centers Regulating Autonomic Function

#### Rostral Ventrolateral Medulla

The rostral ventrolateral medulla (RVLM) plays a pivotal role in the maintenance of baseline sympathetic tone and the short-term regulation of blood pressure.[10] It exerts a continuous excitatory signal on sympathetic preganglionic neurons, thus modulating vascular resistance and cardiac output. When the RVLM function is compromised, this sympathetic drive is lost, leading to profound reductions in systemic vascular resistance and cardiac contractility. As a consequence, patients may experience severe hypotension and an inability to mount an effective sympathetic response during periods of physiological stress, such as hemorrhage or infection. Animal studies have corroborated these effects, showing that RVLM hypoperfusion causes abrupt reductions in mean arterial pressure and heart rate, closely resembling the hemodynamic disturbances seen in neurogenic shock.[10]

#### Nucleus Tractus Solitarius

The nucleus tractus solitarius (NTS) serves as the primary relay center for visceral afferent signals, including those originating from baroreceptors and chemoreceptors, which are essential for the rapid detection of changes in blood pressure and blood chemistry.[11] It plays a central role in autonomic reflex arcs, particularly in the regulation of heart rate, blood pressure, and respiratory patterns. Injury to the NTS disrupts the processing and integration of these critical sensory signals, resulting in impaired autonomic reflex responses such as a blunted cardiovascular compensation to hypotension and hypoxia.[11] This impairment can significantly exacerbate the severity of neurogenic shock by preventing effective activation of the sympathetic outflow necessary to restore circulatory stability. Moreover, neuroplastic changes within the NTS following spinal cord injury have been implicated in persistent

autonomic dysfunction, contributing to chronic cardiovascular and respiratory sequelae observed in patients.[12] These maladaptive neuroplastic alterations can lead to sustained autonomic imbalance, thereby complicating long-term recovery and highlighting the importance of understanding NTS pathology in neurogenic shock and spinal cord injury.

### Dorsal Motor Nucleus of the Vagus

The dorsal motor nucleus of the vagus (DMV) is a key center of parasympathetic output, particularly to the heart and gastrointestinal tract.[13] Under normal conditions, parasympathetic and sympathetic inputs to target organs are balanced. However, in the setting of sympathetic disruption, the unopposed parasympathetic activity originating from the DMV can lead to significant bradycardia, reduced cardiac output, and worsening systemic hypotension.[13] This parasympathetic predominance further destabilizes cardiovascular function during the acute phase of neurogenic shock.[6] Clinical studies have supported this mechanism, showing that increased DMV activity correlates with altered heart rate variability (HRV), reflecting excessive vagal influence in affected patients.[13] These observations emphasize the DMV's central role in autonomic dysregulation and its potential as a therapeutic target in the hemodynamic management of neurogenic shock.

## Spinal Cord and Sympathetic Pathways

### Intermediolateral Cell Column

The intermediolateral cell column (IML), located in the lateral horns of the spinal cord segments T1 through L2, contains the cell bodies of sympathetic preganglionic neurons. These neurons are essential for initiating sympathetic responses that regulate vascular tone, cardiac function, and thermoregulation.[14] Injuries occurring at or above the T6 spinal level can result in a complete disruption of sympathetic outflow below the level of the lesion. This leads to a loss of vasomotor tone, systemic vasodilation, impaired thermoregulatory sweating, and significant hypotension—hallmark features of neurogenic shock.[7] Histopathological studies have demonstrated that the degree of preganglionic neuronal loss within the IML correlates with the severity of autonomic dysfunction observed after spinal cord injury.[14] These findings underscore the IML's essential role in maintaining sympathetic integrity and its central involvement in the development of neurogenic shock.

### Descending Sympathetic Pathways

Descending autonomic fibers arise primarily from hypothalamic and brainstem nuclei and descend through the spinal cord to reach the IML. These fibers coordinate higher level autonomic functions with spinal circuits. Damage to these descending pathways—whether through traumatic, ischemic, or compressive injury—results in disorganized or absent autonomic regulation.[3,7] The resulting loss of sympathetic drive contributes to persistent hypotension and impaired compensatory responses to postural changes.[8] Recent advances in neuroimaging, such as diffusion tensor imaging, have revealed microstructural injuries in these pathways even when conventional imaging appears normal, underscoring their critical role in the pathophysiology of neurogenic shock.[15]

## Peripheral Sympathetic Ganglia and Effectors

Sympathetic chain ganglia are areas where preganglionic neurons synapse with postganglionic fibers that innervate peripheral target tissues, such as blood vessels, the heart, and visceral organs.[6] Disruption of signaling at these ganglia —whether due to direct injury or loss of upstream signals— impairs vascular tone, resulting in systemic vasodilation. This loss of vasomotor control is a central mechanism underlying the development of distributive shock in spinal cord injury patients.[3,7] Consequently, impaired peripheral autonomic signaling plays a major role in the persistent hypotension characteristic of neurogenic shock. Electrophysiological studies support this by revealing impaired neurotransmission within sympathetic ganglia post-injury, highlighting their peripheral role in autonomic failure.[16] Experimental models further demonstrate altered synaptic function and neurotransmitter release in damaged ganglia, offering insights into the cellular mechanisms behind this dysfunction.[16,17] Recognizing these peripheral alterations is essential for developing therapies aimed at restoring autonomic balance and improving clinical outcomes.

### Adrenal Medulla

The adrenal medulla, a modified sympathetic ganglion in shape, releases catecholamines (mainly epinephrine and norepinephrine) directly into the circulation upon sympathetic stimulation.[6] This endocrine release is essential for increasing heart rate, cardiac output, and vascular resistance in states of stress.[7] With spinal cord injury, compromised stimulation of the adrenal medulla reduces this catecholamine response, greatly impairing the body's capacity to compensate for hypotension and shock states.[7] Clinical studies have substantiated this mechanism, demonstrating reduced circulating norepinephrine levels during the acute phase of neurogenic shock, providing clear biochemical evidence of adrenal hypostimulation and highlighting the critical role of adrenal dysfunction in the pathophysiology of neurogenic shock.[18]

## Pathophysiological Consequences of Neuroanatomical Disruption

### Loss of Vasomotor Tone and Hypotension

Sympathetic integrity is necessary to sustain vascular tone by ongoing vasoconstrictor signals.[6] Following interruption of these pathways, uncontrolled vasodilation in the venous and arterial beds ensues. Peripheral pooling of blood, therefore, diminishes venous return to the heart (preload),

reduces stroke volume, and produces severe hypotension.[7] Regarding the absence of sympathetic vasoconstriction, compensatory mechanisms are altered, and circulatory collapse is increased. Recent advances in hemodynamic monitoring, particularly through pulse contour analysis, have quantitatively confirmed the significant decline in systemic vascular resistance characteristic of neurogenic shock, providing critical insights into its pathophysiology and guiding therapeutic interventions.[19] Furthermore, studies utilizing invasive and noninvasive hemodynamic assessments have demonstrated that early detection and tailored management of vascular tone abnormalities can improve hemodynamic stability and patient outcomes in neurogenic shock.[20,21]

### Bradycardia Due to Unopposed Vagal Activity

Sympathetic stimulation in physiological conditions opposes parasympathetic (vagal) action on the heart to maintain proper heart rate and cardiac output. In neurogenic shock, sympathetic mechanisms are disrupted, allowing parasympathetic activity to become unopposed.[6] Vagal predominance is expressed as severe bradycardia, further decreasing cardiac output and adding to the already severe hypotensive state.[13] Severe bradycardia may evolve into asystole if not treated. HRV analysis has proven useful in identifying excessive vagal tone and forecasting bradycardic episodes, supporting its role in the early detection and management of autonomic instability in neurogenic shock.[13,22]

### Impaired Baroreceptor Reflexes

Baroreceptors located in the carotid sinus and aortic arch play a crucial role in continuously monitoring arterial pressure and initiating reflexive adjustments via the ANS.[9] Central disruption of baroreceptor pathways impairs this vital homeostatic mechanism, preventing appropriate increases in heart rate and vasoconstriction in response to hypotension.[10] Consequently, patients experiencing neurogenic shock cannot initiate the compensatory responses typically seen in other types of shock. Neuropathological studies have demonstrated lesions in the nucleus ambiguus and NTS, critical components of the baroreflex arc, which correlate with clinical manifestations of baroreflex failure.[23]

### Secondary Metabolic and Ischemic Effects

The persistent hypotension and hypoperfusion during the neurogenic shock phase are associated with ineffective oxygen delivery to the essential organs. Ischemia activates a cascade of metabolic derangements, lactic acidosis, acute tubular necrosis-related renal failure, hepatic failure, and systemic inflammatory responses.[6] Persistent hypoperfusion continues to cause multi-organ dysfunction syndrome, greatly exacerbating morbidity and mortality unless early intervention is made.[7] Clinical studies have demonstrated that elevated lactate levels and Sequential Organ Failure Assessment scores in intensive care unit patients serve as critical indicators of the metabolic burden and severity associated with untreated neurogenic shock.[24]

## Conclusion

Neurogenic shock neuroanatomy is characterized by a complex interaction between the central and peripheral ANSs. Damage to the crucial autonomic centers in the brainstem and spinal cord results in the characteristic manifestations of neurogenic shock, i.e., hypotension and bradycardia. Understanding these neuroanatomical pathways is key to effective targeted therapeutic intervention toward restoring autonomic balance and better patient outcomes. Adherence to established clinical management guidelines remains paramount for optimizing care, with an emphasis on prompt hemodynamic stabilization and precise autonomic support.[25] Looking ahead, future research must focus on the development of novel pharmacologic agents that selectively target dysfunctional autonomic circuits, alongside personalized rehabilitation approaches designed to reinstate autonomic function and promote long-term recovery.[5,26] Such advances hold promises for transforming the prognosis of patients affected by neurogenic shock.

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Conflict of Interest
None declared.

### References

1 Tyroch AH, Davis JW, Kaups KL, Lorenzo M. Spinal cord injury. A preventable public burden. Arch Surg 1997;132(07):778–781
2 Abdul Azeez MM, Moscote-Salazar LR, Alcala-Cerra G, et al. Emergency management of traumatic spinal cord injuries. Indian J Neurotrauma 2020;17(02):57–61
3 Kwon BK, Tetreault LA, Martin AR, et al. A clinical practice guideline for the management of patients with acute spinal cord injury: recommendations on hemodynamic management. Global Spine J 2024;14(3_suppl):187S–211S
4 Stein DM, Knight WAT IV. Emergency neurological life support: traumatic spine injury. Neurocrit Care 2017;27(Suppl 1):170–180
5 Parra MW, Ordoñez CA, Mejia D, et al. Damage control approach to refractory neurogenic shock: a new proposal to a well-established algorithm. Colomb Med (Cali) 2021;52(02):e4164800
6 Dave S, Dahlstrom JJ, Weisbrod LJ. Neurogenic Shock. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2025
7 Moscote-Salazar LR, Janjua T, Flórez-Perdomo WA, Rukadikar C, Agrawal A. Pathophysiological mechanisms of neurogenic shock. Indian J Neurotrauma 2025;22(02):122–125
8 Vaillancourt M, Chia P, Sarji S, et al. Autonomic nervous system involvement in pulmonary arterial hypertension. Respir Res 2017;18(01):201
9 Valenza G, Sclocco R, Duggento A, et al. The central autonomic network at rest: uncovering functional MRI correlates of time-varying autonomic outflow. Neuroimage 2019;197:383–390
10 Guyenet PG. The sympathetic control of blood pressure. Nat Rev Neurosci 2006;7(05):335–346
11 Wang K, Duan S, Wen X, et al. Angiotensin II system in the nucleus tractus solitarii contributes to autonomic dysreflexia in rats with spinal cord injury. PLoS One 2017;12(07):e0181495
12 Hou S, Duale H, Cameron AA, Abshire SM, Lyttle TS, Rabchevsky AG. Plasticity of lumbosacral propriospinal neurons is associated with the development of autonomic dysreflexia after thoracic spinal cord transection. J Comp Neurol 2008;509(04):382–399

13 Strain MM, Conley NJ, Kauffman LS, et al. Dorsal motor vagal neurons can elicit bradycardia and reduce anxiety-like behavior. iScience 2024;27(03):109137
14 Llewellyn-Smith IJ, Weaver LC. Changes in synaptic inputs to sympathetic preganglionic neurons after spinal cord injury. J Comp Neurol 2001;435(02):226–240
15 Steinman J, Cahill LS, Stortz G, Macgowan CK, Stefanovic B, Sled JG. Non-invasive ultrasound detection of cerebrovascular changes in a mouse model of traumatic brain injury. J Neurotrauma 2020;37 (20):2157–2168
16 Michael FM, Patel SP, Rabchevsky AG. Intraspinal plasticity associated with the development of autonomic dysreflexia after complete spinal cord injury. Front Cell Neurosci 2019;13:505
17 McLachlan EM. Diversity of sympathetic vasoconstrictor pathways and their plasticity after spinal cord injury. Clin Auton Res 2007;17(01):6–12
18 Pastrana EA, Saavedra FM, Murray G, Estronza S, Rolston JD, Rodriguez-Vega G. Acute adrenal insufficiency in cervical spinal cord injury. World Neurosurg 2012;77(3–4):561–563
19 Grensemann J. Cardiac output monitoring by pulse contour analysis, the technical basics of less-invasive techniques. Front Med (Lausanne) 2018;5:64
20 McLean AS. Echocardiography in shock management. Crit Care 2016;20(01):275
21 Taman M, Abdulrazeq H, Chuck C, et al. Vasopressor use in acute spinal cord injury: current evidence and clinical implications. J Clin Med 2025;14(03):902
22 Burzyńska M, Woźniak J, Urbański P, Kędziora J, Załuski R, Goździk W, Uryga A. Heart rate variability and cerebral autoregulation in patients with traumatic brain injury with paroxysmal sympathetic hyperactivity syndrome. Neurocrit Care 2025;42 (03):864–877
23 Biaggioni I, Whetsell WO, Jobe J, Nadeau JH. Baroreflex failure in a patient with central nervous system lesions involving the nucleus tractus solitarii. Hypertension 1994;23(04):491–495
24 Cheranakhorn C, Teeratpatcharakun T. Accuracy of SOFA score to predict outcome in community-acquired sepsis. J Med Assoc Thai 2021;104(04):544–551
25 Moscote-Salazar LR, Janjua T, Agrawal A. The clinical rules for the management of neurogenic shock. Indian J Neurotrauma 2025 (e-pub ahead of print). Doi: 10.1055/s-0045-1802587
26 Brennan FH, Swarts EA, Kigerl KA, et al. Microglia promote maladaptive plasticity in autonomic circuitry after spinal cord injury in mice. Sci Transl Med 2024;16(751):eadi3259

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